SPAWNING OF THE MOUNTAIN GALAXIAS, *GALAXIAS OLIDUS* GÜNTHER, IN BRUCES CREEK, VICTORIA

W. G. O'CONNOR AND J. D. KOEHN

Freshwater Ecology Branch, Department of Conservation and Environment, 123 Brown Street, Heidelberg, Victoria 3084

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In Bruces Creek, Victoria, *Galaxias olidus* had a spawning season extending from early August to late October. Water temperatures ranged between 8° and 10.2°C over this period. Fertilized eggs were mainly found attached to the underside of boulders in riffles but some eggs were also found lodged amongst substrate or drifting downstream. *G. olidus* had a relatively low fecundity with an average of 198 eggs per female. Average egg diameter was 2.3 mm. All *G. olidus* were mature in their second year, although males matured earlier than females. The population had an overall sex ratio of 1:1 but the sexes were unevenly distributed, with more males in 0+ and more females in 2+ and 3+ year classes. The preferred habitat of adults was in pools. Fertilized eggs collected from the stream at an early stage of embryonic development hatched in the laboratory after 21 days at temperatures between 12.9° and 14.8°C. Newly hatched larvae averaged 9.4 mm in length.

THE MOUNTAIN GALAXIAS, *Galaxias olidus* Günther, a small (less than 145 mm long) native freshwater fish of the family Galaxiidae (McDowall 1980a), is generally found in small, headwater streams (Berra 1973, Fletcher 1979, Jackson 1981) at altitudes up to 1800 m (McDowall & Frankenberg 1981). The species occurs from southern Queensland to south-eastern South Australia (Merrick & Schmida 1984), although it has been recognized as having a highly fragmented distribution, often occurring in small isolated populations (Tilzey 1976, Cadwallader 1979, Jackson & Davies 1983, Cowden 1988).

G. olidus is widespread throughout Victoria (Cadwallader & Backhouse 1983), where its conservation status is "indeterminate" (Koehn & Morison 1990) due to uncertainty about the taxonomic status of the various taxa in this species complex. The population of this complex occurring in Bruces Creek conforms to the "typical" *G. olidus* form (see Cadwallader & Backhouse 1983). Although most of this taxon is common and widespread, *G. olidus* var. *fuscus* has been categorized as endangered in Victoria (Koehn & Morison 1990) and nationally (Jackson 1991).

Until recently there had been little investigation of the life history of *G. olidus* (Koehn & O'Connor 1990a). Most information remains unpublished in university theses (Harasymiw 1970, Fletcher 1979, Cowden 1988, Drayson 1989). The present paper contains information on the spawning of *G. olidus* in a small Victorian stream and includes data on habitat, population structure, sexual maturity, fecundity, spawning season and site, egg description, incubation period, and description of larvae.

STUDY SITE

The study was conducted in the upper reaches of Bruces Creek, Victoria, approximately 47 km north-east of Melbourne (Fig. 1), where McKenzie & O'Connor (1989) found a large population of *G. olidus*, the only fish species present. The absence of other species, particularly predatory species such as brown trout, *Salmo trutta*, was considered important as it allowed instream distribution and habitat preferences to be unaffected. *S. trutta* has been implicated in the displacement of *Galaxias olidus*, *G. truttaceus* and *G. brevipinnis* from preferred habitat areas (Koehn unpubl. data).

Bruces Creek rises on the western slopes of Mt Disappointment in the Great Dividing Range and flows firstly in a southwesterly then south-easterly direction to its confluence with the Plenty River. The study site was about 6.5 km downstream from the source of Bruces Creek at an altitude of 340 m. At the site, Bruces Creek is a small, shallow, third order stream with an average width of 2.0 m, an average depth of approximately 0.3, and consisting of alternating pools and riffles. The stream is in a relatively natural

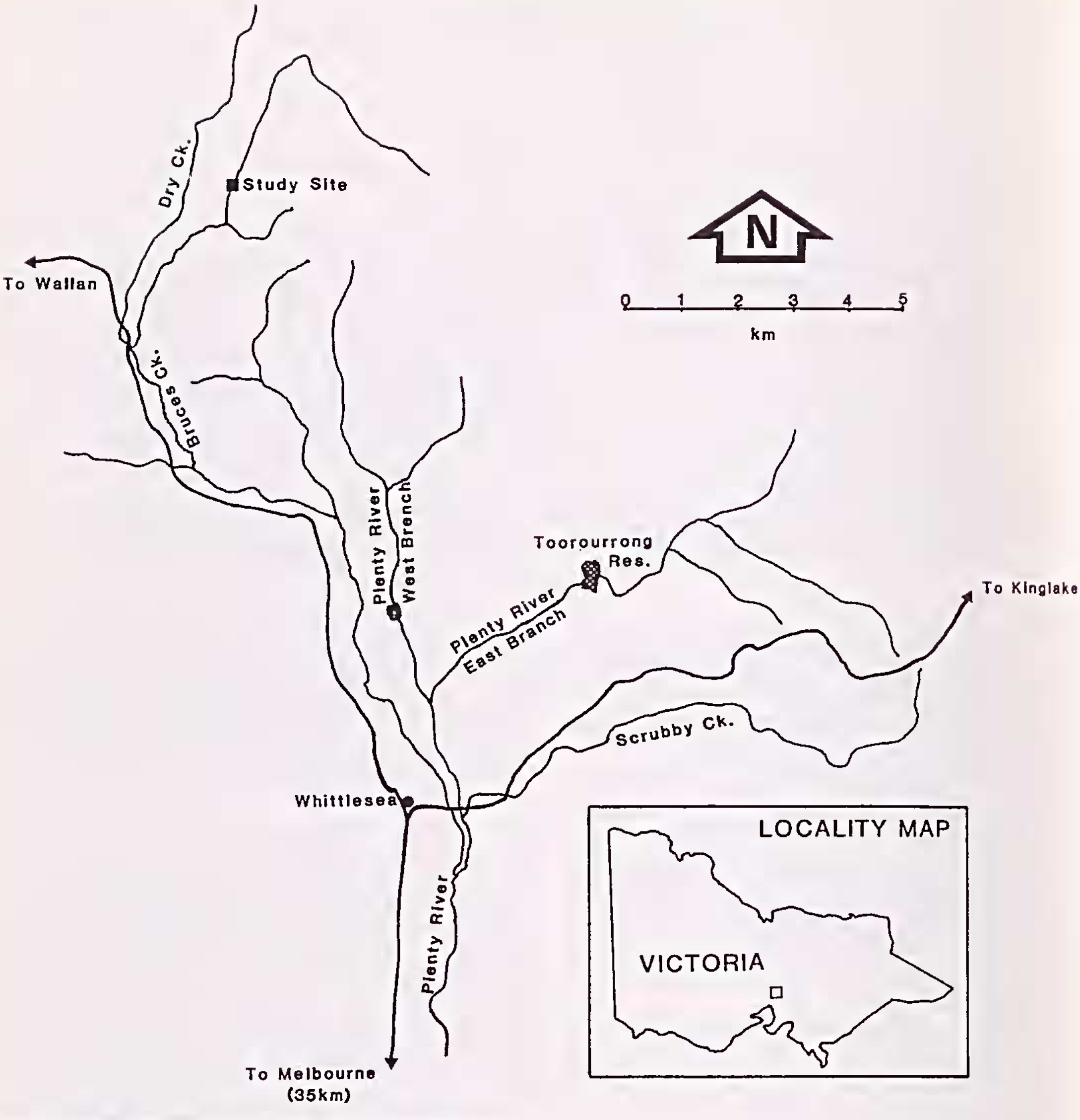

Fig. 1. Map showing the study site at Bruces Creek.

condition and contains abundant instream cover and wood debris.

Beardsell (pers. comm.) described the bank vegetation at the site as mountain grey gum riparian damp sclerophyll forest (with no alien flora species) and the hillside vegetation as dry sclerophyll. The surrounding land is State Forest.

METHODS

G. olidus was collected from Bruces Creek on 11 occasions between 15 August 1990 and 25 October 1990 to examine spawning condition. This sampling period was selected as it coincided with previously reported spawning periods (Koehn & O'Connor 1990a). The length of stream fished for each sample ranged from 15 m to 60 m, and the number of fish collected in each sample varied from 22 to 62. Samples were taken over a 380 m stretch of stream, with only one section being sampled on each occasion. On 11 July 1991 an additional 24 ripe female fish were collected to determine egg numbers.

An estimate of the proportion of fish collected from pools and riffles was made during these collections. On 4 October 1990 and 25 October 1990 sampling was conducted to determine population densities and on 11 July 1991 an additional 43 m stream section containing 5 pools and 4 riffles was sampled to determine pool or riffle preferences. Fish were captured from one electrofishing run, moving upstream using 2 operators, one with a dip net and polaroid glasses. Pools and riffles were separated by stop nets and the wetted perimeter of each section was measured and the area calculated. Fish numbers were adjusted using electrofisher efficiencies provided in Koehn & McKenzie (1985).

All fish sampling was conducted using a Smith Root Model 12 backpack electrofisher operated at settings of 120 Hz and 600 or 700 V. The length to caudal fork (LCF) of each fish was measured to the nearest mm and the spawning condition of each fish was assessed as per maturity stages in Pollard (1972).

Water temperature and conductivity were recorded during each sample using a Yellow Springs Model 33 Conductivity/Temperature meter. Relative water level was measured at a fixed depth gauge on each visit. The habitat at each spawning site was described. In determining pool or riffle preferences (11 July), stream length, width and depth were measured along with observations of the location of each fish collected. Water velocities were measured 100 mm above the substrate using an Ott mini flow meter. Substrate particles were assessed visually, according to the size categories of Cummins (1962).

Fecundities were determined for 7 ripe females collected on 15, 22, 29 August 1990 and for 24 females collected on 11 July 1991 by dissecting gonads, prising eggs apart and counting individually.

Egg searches were carried out in both pools and riffles in the stream by the following methods:

(1) by inspecting instream habitat such as substrate and wood debris for attached eggs;

(2) by using drift nets of mouth opening 35 × 17 cm mesh mm (Hellawell 1986) positioned in the stream for (a) 3 hours and 22 hours where there had been no upstream disturbance of the streambed, and (b) several minutes, 0.5 to 2 m downstream from where substrate or instream cover had been gently disturbed (e.g. by lifting cobbles).

Collected samples were inspected visually for the presence of eggs. Diameters of 50 oocytes and of 28 fertilized eggs collected from the field, and lengths of 16 newly hatched larvae, were measured to the nearest 0.01 mm using a Nikon Profile model 6C-2 projector at a magnification of 10×.

Eggs collected in the field by the above methods were transferred to hatching baskets in the aquaria and the time taken to hatch was recorded. The hatching baskets consisted of 80 mm lengths of 90 mm diameter PVC pipe covered at one end with 0.5 mm nylon mesh netting. These baskets were suspended vertically in a 20 L aquarium tank with a through flow of approximately 27 L/h of filtered, dechlorinated water (aquarium water) (see Bacher & O'Brien 1989). Water temperatures were maintained between 12.3° and 14.9°C.

Sixty larvae hatched from collected eggs were placed in three 4 L tanks (20 per tank) filled with static, aerated aquarium water kept at ambient temperatures of 15.0°C to 17.2°C and the time taken to use up their yolk sacs observed.

The time to first feed was determined by placing 20 5-day-old larvae which had used their yolk sac in a tank to which 250 mL of water from a swamp containing abundant plankton was added. Larvae and water were then removed to a beaker twice daily and any feeding activity observed using a stereomicroscope. Guts were checked for food particles.

RESULTS

Habitat preferences

It was estimated that more than 90% of *G. olidus* collected in 1990 were from pools containing areas where water velocities were 0–0.15 m/sec, depths were 0.4–0.7 m, and there was abundant instream cover in the form of wood debris, submerged tree roots and undercut banks. The substrate of pools varied from predominantly silt/clay to boulder and cobbles. Sampling of 5 pools and 4 riffles on 11 July 1991 showed that 87% of *G. olidus* came from pools. Calculated on a per area basis, 85.5% of *G. olidus* occurred in pools and only 14.5% in riffles.

Two sections of the stream 22 m and 95 m long were electrofished on 4 October and 25 October 1990. Population densities of 1.09 and 0.84 fish/m^2 respectively were removed from one electrofishing run. Koehn & McKenzie (1985) recorded a 64% capture efficiency for common galaxias, *Galaxias maculatus*, from one electrofishing run using a Smith Root MKVIA electrofisher. These trials were conducted on a similar species, of similar size, under comparable conditions, with equipment considered to be of similar efficiency. The population densities for *G. olidus* were thus adjusted by a factor of 1.56 to give calculated population densities of 1.70 and 1.31 fish/m^2 respectively.

Population structure

In the length–frequency histogram for the *G. olidus* population (Fig. 2), four size classes were recognised (Table 1). Following Fletcher (1979) these size classes were assigned estimated age classes of O+, 1+, 2+ and 3+ years, with O+ being assigned to juveniles from the 1989 spawning. In the 263 fish captured, the size ranged from 36 mm to 100 mm LCF, the largest fish being ripe females.

Further analysis of the age classes (Table 1) shows that the population was dominated by the 1+ age class, although the smaller O+ age class was likely to be under-represented due to less efficient sampling of smaller fish (Koehn & McKenzie 1985). Only 2.3% of the population were 3 years or older, indicating that few fish live beyond their third year.

Details of sexual maturity for each age-class are given in Table 1. Most *G. olidus* do not reach sexual maturity in their first year (0+) when only 20% of male and 5% of female fish were sexually mature. The smallest sexually mature male was 42 mm (LCF) and the smallest female was 47 mm LCF. All fish were sexually mature by their second year (1+).

The overall sex ratio of mature fish in the population was 1 : 1 but the ratio of sexually mature individuals was not consistent throughout the age-classes. The earlier maturity of some O+ male fish increased the apparent male : female ratio in that class. The 1+ class showed a 1.1 : 1 ratio whereas the 2+ class showed a 1 : 4.0 ratio. All six fish in the 3+ class were female.

The 31 ripe female *G. olidus* analysed for fecundity ranged between 55 mm and 88 mm LCF (mean 66 mm) and contained from 44 to 384 eggs (mean 198, N = 31, SE = 15). Number of eggs of *G. olidus* is positively correlated to fish length ($r = 0.836$, $p < 0.01$) (Fig. 3).

Spawning season

The spawning season for *G. olidus* in Bruces Creek in 1990 extended from early August to about late October. The percentage of spent fish in each sample increased from 10% to 93% during the study (Fig. 4). Although spawning had already begun by the start of the study, this sam-

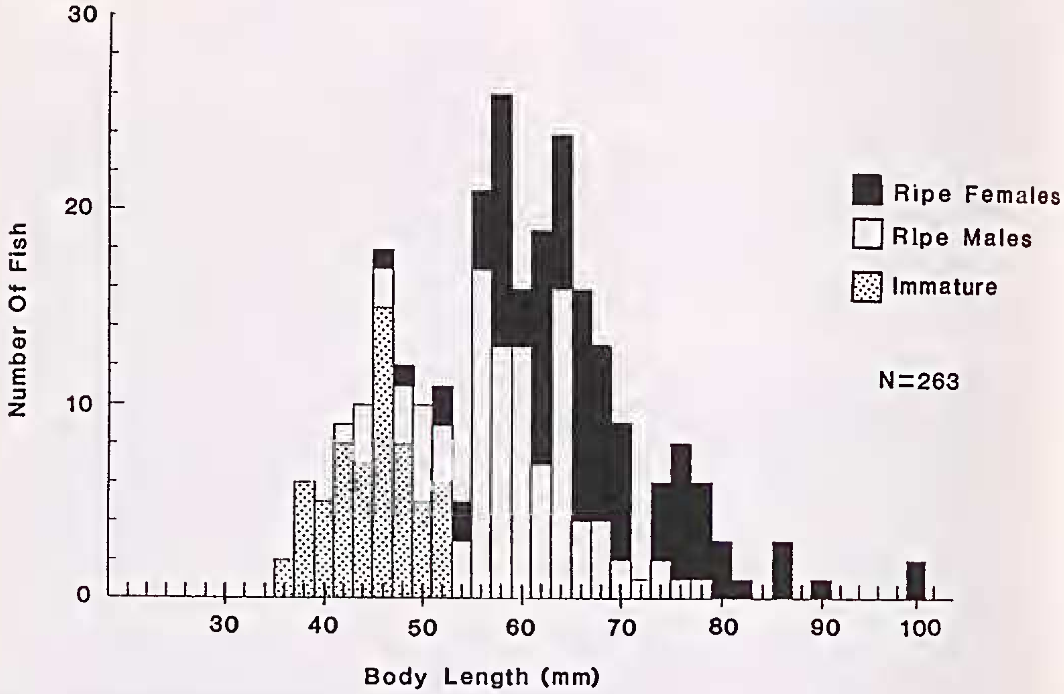

Fig. 2. Length–frequency histogram for *Galaxias olidus* in Bruces Creek in 1990.

Age Class	Length Range (mm)	Fish Nos	% Popn	Ripe Males No.	Ripe Males %	Ripe Females No.	Ripe Females %	Immature Fish No.	Immature Fish %	Male: female ratio
0+	36–52	83	31.6	17	20.5	4	4.8	62	74.7	4.1:1
1+	53–72	150	57.0	8.0	53.3	70	46.7	0	0	1.1:1
2+	73–82	24	9.1	4	16.7	20	83.3	0	0	1:4.0
3+	83–100	6	2.3	0	0	6	100	0	0	N/A
Total		263		101		100		62		1.0:1

Table 1. Length range, number of fish collected, percentages of ripe males, females and immature fish, and sex ratios for each age class of the *Galaxias olidus* population during the 1990 spawning season in Bruces Creek.

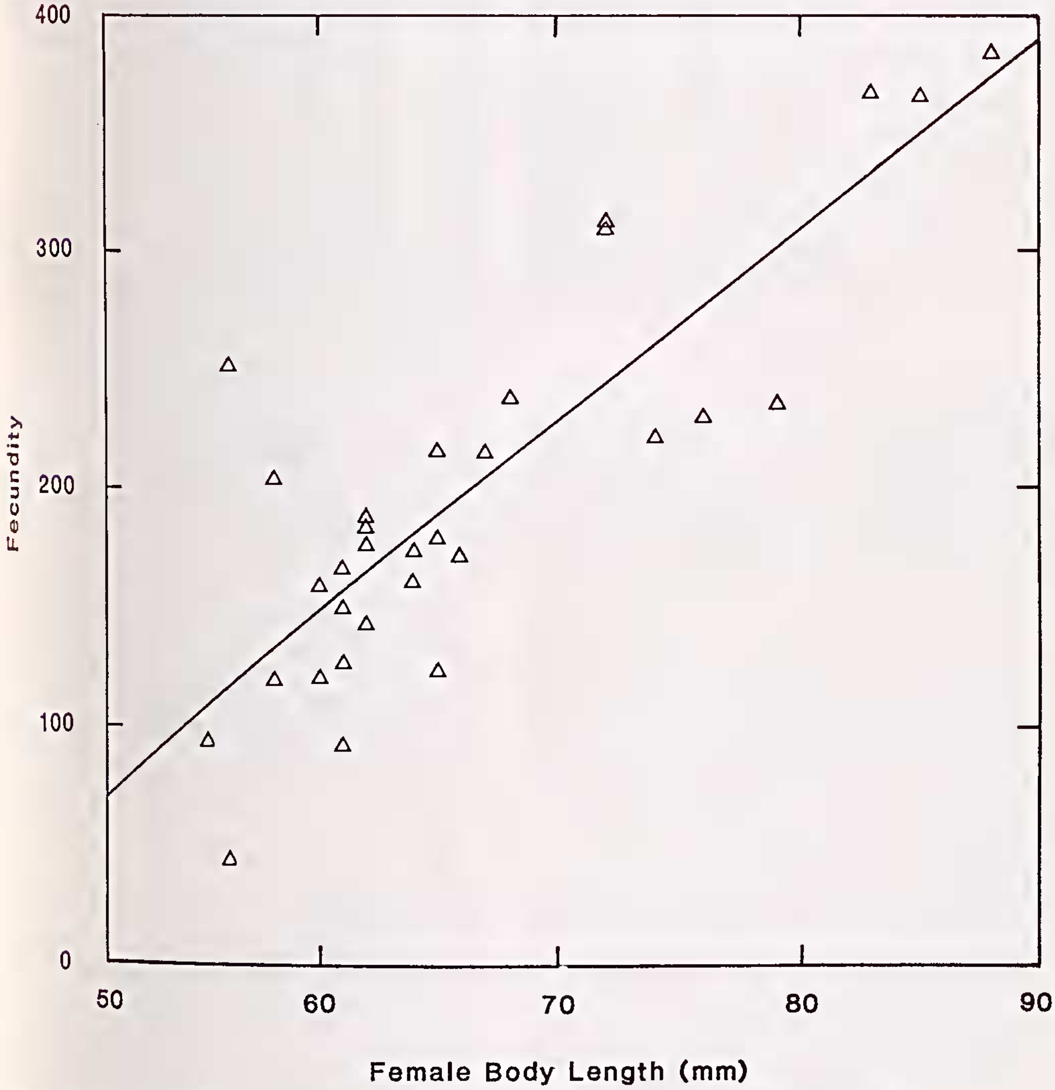

Fig. 3. Relationship between length and fecundity for *Galaxias olidus* females in Bruces Creek.

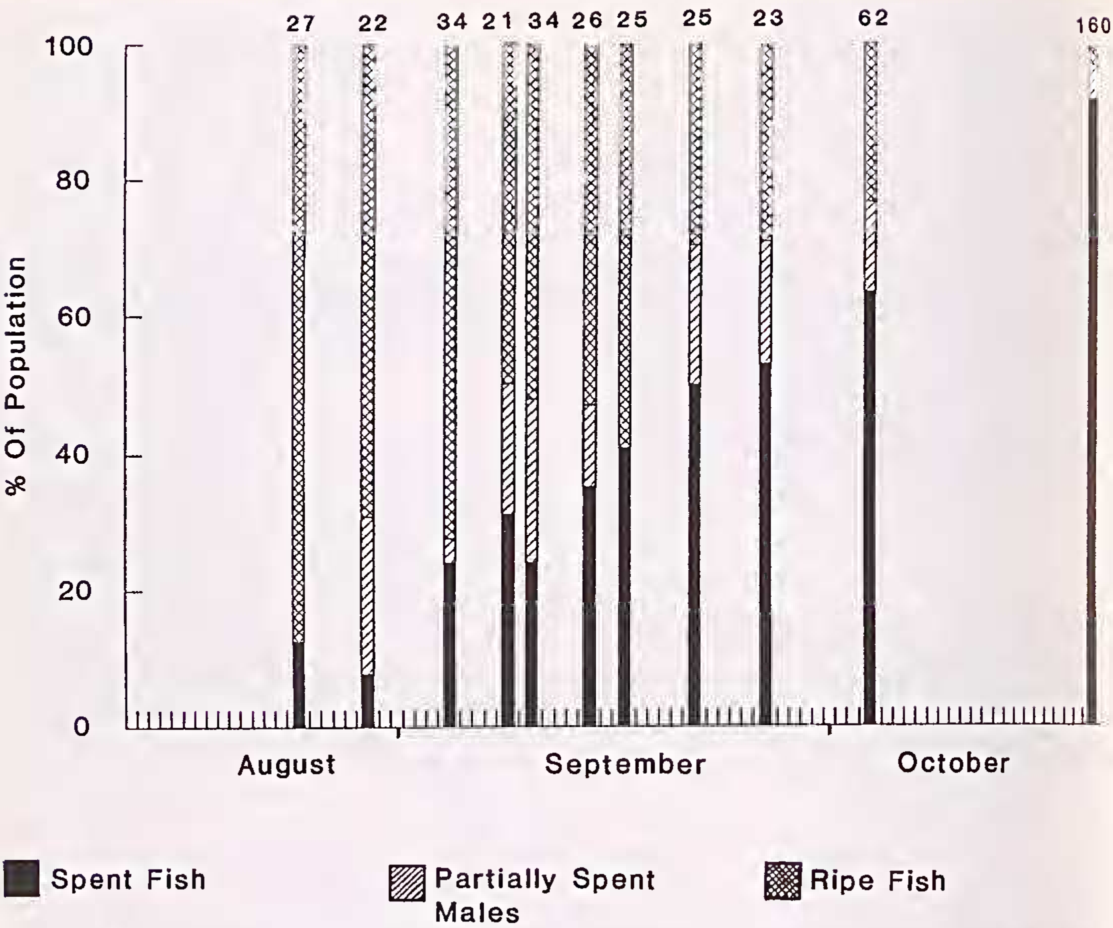

Fig. 4. Percentage of ripe and spent *Galaxias olidus* during the 1990 spawning season in Bruces Creek. Numbers of fish examined are given above each column.

pling period covered most of the spawning season.

Most females collected were either ripe or spent, only two being part spent, an indication that females lay all their eggs at once. Both part spent females had red bruising on their sides and abdomen suggesting they may have been in the act of spawning when captured. Several other females (spent and running ripe) and males (part spent) had similar marks.

Eggs in some gravid females in the 4 October sample and in all gravid females in the 25 October 1990 sample were noticed to be smaller in size, possibly indicating that a small percentage of females did not spawn and were undergoing involution. Throughout the breeding season a proportion of males were partially spent, suggesting that each male may be involved in more than one fertilization.

Daytime water temperatures between 15 August 1990 and 4 October 1990 were between 8.0° and 10.2°C and water levels rose to a maximum recorded level of 70 mm above the normal watermark, although observations indicated that higher short-term levels did occur. Water temperature was 13.5°C on 25 October 1990. Water conductivities varied from 73 to 90 EC units.

Spawning sites

Four individual spawning sites were found: three were at the downstream end of a riffle at the head of a pool containing large numbers of ripe fish, and one was at the head of a riffle immediately downstream of a pool. No fish were collected from the near vicinity of any of the spawning sites.

Eggs were found adhering strongly to the underside of boulders larger than 180 mm in diameter situated in riffles immediately upstream and downstream of pools. Eggs were not found attached to wood debris or other instream objects.

The underside of each boulder was relatively flat but slightly raised (up to 60 mm) from the streambed so that the eggs were sheltered from the main water current. Water velocities in the riffles around the boulders ranged from approximately 0.2 to 0.5 m/sec. On two boulders which had not been disturbed 179 eggs and 26 eggs were counted. Eggs were attached either singly or in groups of 6 to 62; the eggs were usually one and not more than two layers thick and were coated with sand and gravel particles. The boulder with 179 eggs contained eggs at three different stages of embryological development.

In four drift nets set for 3 hours below undisturbed sites only one egg was collected. A repeat set of that net 2 days later at the same site collected one more egg. The net had been positioned in the main gently flowing current (0.1 m/sec) about 1.5 m downstream of a riffle. No eggs were collected in two nets set overnight for 22 hours.

When substrate or instream objects such as wood debris were disturbed by gentle lifting two eggs were caught in one drift net and nine in another held immediately downstream of two riffles. The substrate of these two riffles comprised boulder 10%, cobble 40%, pebble 30% and gravel 20%. One egg was collected from a pool with a "flat" streambed whose substrate comprised sand/silt 70%, boulder 10%, and cobble 10%. No eggs were found in four other pools and three other riffles "searched" in the same manner.

We surmise that most eggs of *G. olidus* are attached to the underside of boulders, but some eggs come to rest in the substrate and a few drift downstream.

Egg description and incubation period

Unfertilised oocytes were spherical, demersal, white or opaque and adhesive. Fertilized, water hardened eggs were spherical, demersal, transparent and initially adhesive but single, unattached eggs became progressively less adhesive.

The diameters of oocytes and fertilized eggs at the earliest stages of development and at the "eyed" stage were:

Mean oocyte diameter = 2.29 mm (N = 50, SE = 0.22 mm)
Mean egg (early stage) diameter = 2.4 mm (N = 8, SE = 0.11 mm)
Mean egg (eyed) diameter = 2.29 mm (N = 20, SE = 0.20mm).

Three eggs collected on 5 September 1990 were at the earliest stage of embryological development (i.e. no embryo in nucleus) and took 21 days to hatch at temperatures of 12.9–14.8°C. All other viable eggs collected were at later stages of development and hatching times were 9–14 days at 14.0–15.0°C.

Larvae

The lengths of larvae measured 0–6 hours after hatching ranged from 9.0 mm to 9.8 mm TL. Mean length was 9.39 mm (N = 16, SD = 0.26). The larvae had small yolk sacs 1.4 mm long. In the light, these larvae were active swimmers throughout the water column including at the surface, but they also lay motionless on the bottom of the tank for several minutes. Larvae appeared to have absorbed their yolk sacs after 5 days and commenced feeding 3 days later.

DISCUSSION

Our study provided information on *G. olidus* from relatively natural surroundings unaffected by major habitat alterations or by other fish species including introduced predators. The major habitat preference of *G. olidus* in Bruces Creek was clearly for pool areas with slow-flowing, deeper water in a stream containing abundant instream habitat of wood debris, submerged tree roots and undercut banks and intact riparian vegetation. Such attributes in streams have been recognised as important for freshwater fishes (Cadwallader & Backhouse 1983, OCE 1988, Lloyd & Walker 1988, Koehn & O'Connor 1990a, 1990b). Riparian vegetation prevents erosion, provides instream habitat and shading, as well as terrestrial invertebrates which form an important element in the diet of *G. olidus* (Cadwallader et al. 1980). McDowall (1980b) has suggested that removal of riparian vegetation correlates with the reduction in population numbers of several galaxias species in New Zealand.

The relatively high population densities of *G. olidus* (1.31–1.70 fish/m^2) in Bruces Creek are comparable to those of 0.79 and 2.83 fish/m^2 reported by Fletcher (1979) in Watchbox Creek and at Mt Buffalo. Tilzey (1976) reported densities of up to 3.7 fish/m^2 in tributaries of Lake Eucumbene. Such densities are likely to be attributable to the presence of high-quality habitat and the absence of brown trout, *Salmo trutta*. The effects of *S. trutta* on the abundance and distribution of *G. olidus* have been comprehensively documented, with mutually exclusive populations often occurring and a fragmentation of the range of *G. olidus* resulting in isolated populations often being reported (Tilzey 1976, Cadwallader 1979, Fletcher 1979, Jackson & Davies 1983, Cowden 1988, Jones et al. 1990, Lintermans & Rutzou 1990).

After using otoliths to age *G. olidus*, Cowden (1988) concluded that most individuals did not reach maturity until their third year (age 2+). Drayson (1989), however, examined otoliths from *G. olidus* collected in the same catchment as Cowden and considered their annular patterns to be uneven and therefore unsuitable as a means of accurately aging this species. From the length frequency distribution (Fig. 2), we suggest estimated age classes O+ (1st year), 1+ (2nd year), 2+ (3rd year) and 3+ (4th year) based on a similar population structure reported by Fletcher (1979). These three age classes make up almost the entire population (97%) of *G. olidus* in Bruces Creek. Most *G. olidus* did not mature in their first year but all were mature by their second year. These results are consistent with those of Fletcher (1979), namely that maturity is mostly reached at age (1+) and that the maximum age is probably 4 years.

Although the sex ratio for sexually mature fish is 1:1, the ratio is not consistent throughout the age classes. Males mature earlier than females but appear to have a higher mortality; consequently females predominate in the 2+ and 3+ age classes. Cowden (1988) also reported a 1:1 sex ratio.

The fecundity of *G. olidus* is one of the lowest among galaxias species in Australia. A mean fecundity of 198 found in this study is similar to the value of 243 recorded by Cowden (1988). Of Victorian galaxiid species, only *Galaxiella pusilla*, a wholly freshwater species, has a similar fecundity (generally 100–200; Humphries 1986). Fecundities of diadromous galaxiid species are generally much higher: common galaxias, *Galaxias maculatus*, up to 13,500 (McDowall 1968); spotted galaxias, *G. truttaceus*, up to 16,000 (Humphries 1989); and broad-finned galaxias, *G. brevipinnis*, up to 23,000 (Koehn and O'Connor unpubl. data).

The breeding season of *G. olidus* has been variously reported as winter through to summer (Cadwallader & Backhouse 1983). *G. olidus* spawns in October in Victorian alpine streams (Fletcher 1979); from early August to early September in the Australian Capital Territory; and during late August to early September in southern Queensland (Marshall 1989). The variation in onset of these spawning seasons may be due to the corresponding differences in water temperatures. Cowden (1988) recorded temperatures of 6.5–8.2°C, whereas Marshall (1989) estimated a temperature range of about 15–20°C. In Bruces Creek the main breeding season extended for over 2 months from early August to about mid October, when the temperature range was 8.0–10.2°C.

G. olidus employed a spawning strategy indicative of a fish species that has a low fecundity and needs to maximise the survival of eggs and larvae. This strategy involves laying a small number (average fecundity of 198) of relatively large (2.3 mm) adhesive eggs in a protected site, usually a boulder more than 180 mm in diameter and with a narrow gap between the underside of the boulder and the streambed. Similar spawning sites for *G. olidus* have been reported by Cowden (1988). In Bruces Creek the eggs were attached to the underside of the boulders where they may be protected from possible predators (especially fish), disturbance, strong water currents and possible smothering by sediment. All the boulders were in riffles where the surrounding water was relatively fast-flowing (0.2–0.5 m/sec) and well oxygenated. Eggs were not found attached to any other instream objects such as wood debris.

Red bruising on the abdomen and sides of many spawning fish of both sexes suggests that the fish rubbed against hard objects during spawning. Bruising is highly likely in enclosed locations where the fish would probably have to press hard against the underside of boulders in a lateral or upside down position to deposit eggs and milt.

A least three different stages of embryonic development were recorded for eggs at one spawning site. Because females appear to lay all their eggs at once, it appears that more than one spawning may take place at a suitable site. The strategy of laying a small number of relatively large, adhesive eggs at an enclosed site has been described for another Victorian freshwater fish, the freshwater blackfish, *Gadopsis marmoratus* (Jackson 1978). *G. marmoratus* attaches its eggs to the inside of hollow logs which are then guarded by an aggressive male fish (Koehn unpubl. data). Parental care of eggs appears unlikely for *G. olidus* as relatively few fish were collected from the riffle areas and there was no evidence of eggs being guarded. We surmise that ripe males and females from the pools move into the riffles to spawn, then return to their preferred habitat. The collection of eggs in drift nets from both disturbed and undisturbed sites indicates that not all eggs are attached to the spawning site. Such "free" eggs may originate in three ways.

1. Eggs not becoming successfully attached to the spawning site during spawning. This may be expected when fish are attempting to attach and fertilise eggs on the underside of a boulder. There appears to be a large discrepancy between female fecundities and the number of eggs found attached to boulders, suggesting that not all eggs become attached.
2. Eggs being laid at less sheltered sites in the stream where attachment does not occur or where the eggs may easily be displaced. There is, however, no evidence for such sites.
3. Eggs being dislodged from the spawning boulder. This appears unlikely as the eggs adhere strongly to the rock and to each other. Some dislodgement may be possible, however, if subsequent spawning activity occurs at the same site.

The collection of single, non-adhesive, developing eggs at undisturbed sites suggests that some eggs may be carried downstream either by drifting in the current or by rolling along the streambed. Such a mechanism would aid downstream dispersal. *G. olidus* eggs are initially very adhesive, but those at a later stage of development that were unattached were non-adhesive. Some of these eggs probably lodge in the interstices of the substrate in riffles or settle to the streambed in pools. Such eggs were collected by disturbing the substrate.

Hence, the eggs of *G. olidus* may be found in three situations: (a) attached, (b) lodged in the substrate, or (c) drifting. Each of these situations involves a different degree of disturbance to the egg itself, possibly leading to variations in hatching times. Cowden (1988) found that hatching of eggs could be induced by gently swirling the water in which they were held. The induced hatching of eggs of *G. truttaceus* and *G. brevipinnis* by disturbance has also been noticed (Koehn & O'Connor unpubl. data). Cowden (1988) recorded, however, that "induced" fry were smaller and less active than normal.

Exact hatching times were not obtained, but fertilized eggs collected in the stream at an early embryonic stage took 21 days to hatch at temperatures of 12.9° to 14.8°C. Using Cowden's (1988) results, hatching times were estimated to be 47 days at about 9°C and 32 days at about 13°C. Average temperatures in Bruces Creek from August to mid October were about 9°C, while temperatures in late October were about 13°C. Assuming hatching is temperature dependent, these figures suggest that hatchings in Bruces Creek probably occurred from early October until mid December.

Newly hatched larvae emerged at 9.4 mm TL with relatively small yolk sacs which were fully absorbed after about 5 days, with feeding commencing after a further 3 days. Large, well developed larvae with small yolk sacs are more mobile, able to seek shelter and hence less vulnerable than smaller fry with large yolk sacs. This is consistent with the spawning strategy we have described for *G. olidus*.

Increased sediment input into streams has been recognised as having adverse effects on Victorian native freshwater fish (Cadwallader & Backhouse 1983, OCE 1988, Mitchell 1990, Koehn & O'Connor 1990a, 1990b). Sedimentation would be likely to fill or cover potential spawning sites, and the availability of sites under boulders appears essential for spawning. If such sites were not available or were heavily silted so that eggs do not adhere, spawning may not occur or may have reduced success. Likewise, the loss of interstitial spaces in the substrate due to sedimentation may cause increased mortalities to unattached eggs which normally become lodged there. Eggs of *Gadopsis marmoratus, Galaxias truttaceus* and *G. brevipinnis* have shown high mortalities when covered with light layers of silt (Koehn & O'Connor unpubl. data).

Sedimentation and the well-documented threat of predation by introduced species are likely to be major environmental threats to *G. olidus* in otherwise natural streams.

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